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Performance Analysis and Error Detection in 10m Air Pistol Shooting

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***Abstract*— This paper presents an automated system for analyzing ten-shot pistol shooting targets using computer vision and statistical analysis. The proposed method processes a scanned or photographed target image to detect pellet holes, convert shot positions into real-world target coordinates, and evaluate shot grouping characteristics. A rule-based knowledge system is used to classify shooting errors into mechanical, physical, and mental categories and provide corrective recommendations. The system ensures objective, repeatable, and competition standard analysis, making it suitable for learning from the shooter's errors and mistakes.**

***Keywords*— Pistol shooting analysis, Computer vision, OpenCV, Target image processing, Shot detection, Analysis, Error detection, Sports analytics.**

I. Introduction

Pistol shooting is a precision-based sport in which even minor deviations in technique can significantly affect performance. Accurate analysis of shot placement is essential for identifying errors related to trigger control, grip stability, breathing patterns, and mental focus. Traditionally, shooting performance evaluation is performed through manual inspection of paper targets by coaches, a process that often relies on experience and subjective judgment.

Recent advancements in computer vision and image processing have enabled automated analysis of shooting targets. Digital processing of target images facilitates the detection of pellet holes and extraction of quantitative information such as shot coordinates, grouping patterns, and dispersion characteristics. This approach provides objective, repeatable, and detailed performance evaluation compared with conventional manual assessment methods.

This paper presents an automated ten-shot pistol target analysis system using computer vision and rule-based classification techniques. The proposed system detects pellet holes from a target image, converts pixel coordinates into real-world measurements, analyses shot grouping characteristics, and classifies shooting errors into mechanical, physical, and mental categories. The system is designed to assist shooters and coaches by providing reliable and interpretable feedback that can improve training efficiency and overall shooting performance.

Existing shooting analysis methods rely heavily on manual target inspection, leading to subjective evaluation and inconsistent feedback.

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Although electronic target systems offer accurate and detailed performance analysis, their high cost limits accessibility for many shooters, training centres, and educational institutions. Therefore, there is a need for a low-cost automated solution capable of detecting pellet impacts, analysing shot patterns, identifying shooting errors, and generating corrective recommendations using only target images.

II. Problem Statement

Traditional shooting performance evaluation relies heavily on manual inspection of paper targets by coaches, making the process subjective and dependent on individual experience. Although electronic target systems provide accurate and detailed analysis, their high-cost limits accessibility for many shooters, training centres, and educational institutions. Furthermore, most existing image-based scoring systems focus primarily on score calculation and do not provide meaningful insights into the underlying causes of shooting errors. Therefore, there is a need for a low-cost automated system capable of detecting pellet impacts, analysing shot grouping characteristics, identifying mechanical, physical, and mental shooting errors, and generating corrective recommendations to improve training effectiveness and shooting performance.

A. Contributions of the Proposed Work

The major contributions of the proposed work are as follows:

- Development of a low-cost computer vision-based system for automated analysis of 10m air pistol shooting targets.
- Automatic detection and localization of pellet holes from scanned or photographed target images using image processing techniques.
- Conversion of detected shot positions from pixel coordinates to real-world target coordinates for accurate performance evaluation.
- Statistical analysis of shot grouping characteristics, including group centre, group size, radial distance, and shot dispersion.
- Rule-based classification of shooting errors into mechanical, physical, and mental categories based on observed shot patterns.
- Generation of interpretable corrective recommendations to assist shooters and coaches in improving training effectiveness and shooting performance.

III. Literature Survey

Araújo et al. [1] presented a real-time image-based target shooting scoring system that utilizes computer vision techniques to automatically evaluate shooting performance. While the system provides accurate scoring, it primarily focuses on score computation and does not perform detailed error analysis of shooting patterns.

Rudzinski and Luckner [2] developed a low-cost computer vision-based automatic scoring system for shooting targets. Their work demonstrated the feasibility of replacing expensive electronic targets with image processing methods; however, it is limited to scoring applications and does not provide performance diagnostics.

Liu et al. [5] introduced an intelligent shooting action correction method using computer vision. Although the approach provides valuable feedback regarding shooting actions, it focuses primarily on motion analysis rather than target-based performance evaluation.

Kim and Park [6] proposed an AI-based firing skill evaluation system for small arms training. Their work demonstrates the potential of artificial intelligence in shooting assessment; however, the system requires specialized infrastructure and is less suitable for low-cost deployment.

Novak et al. [7] applied machine learning techniques to analyse shooting performance in modern pentathlon events. While the method improves performance prediction, it depends on large datasets and computationally intensive training processes.

Mendes-Neves et al. [8] presented a comprehensive survey of advanced computer vision techniques used in sports analytics. The study highlights recent developments in vision-based performance analysis but does not specifically address precision shooting applications.

The literature review indicates that existing systems primarily focus on scoring, performance prediction, or motion analysis. Very few studies combine computer vision, statistical analysis, and rule-based error classification to provide interpretable feedback from target images. The proposed work addresses this gap by developing a low-cost automated target analysis system capable of detecting pellet holes, analysing shot grouping characteristics, classifying shooting errors, and generating corrective recommendations.

IV. Methodology

A. Components

The proposed system consists of both software and logical components required for automated pistol target analysis. The primary software components include the Python programming environment and the OpenCV library for image processing. Standard Python libraries are used for mathematical computations and statistical analysis.

The logical components of the system include the image acquisition module, image preprocessing module, shot detection module, coordinate transformation unit, statistical analysis unit, and rule-based error classification module. Each component performs a specific task and passes its output to the next stage, ensuring modularity and ease of maintenance.

B. Architecture

The system follows a sequential and modular architecture. The input target image is first processed by the image preprocessing block, where noise reduction and thresholding are performed. The output is then passed to the shot detection block, which identifies pellet hole locations using contour analysis.

Detected shot coordinates are converted from pixel space to real-world target coordinates and forwarded to the statistical analysis block. This block computes group center, group size, and dispersion parameters. Finally, the rule-based error classification module analyzes the statistical results to identify mechanical, physical, and mental errors and generates corrective feedback. The architecture ensures smooth data flow and reliable analysis.

C. Working Methodology

The working of the proposed system begins with the acquisition of a target image captured using a camera or scanner. The input image is pre-processed by converting it into grayscale and applying thresholding techniques to reduce noise and enhance pellet hole visibility. Contour detection is then performed to identify pellet impact locations on the target.

The detected pellet holes are represented by their centroid coordinates in pixel space. These coordinates are converted into real-world target coordinates using a predefined scaling factor. Statistical parameters such as group centre, group size, mean radial distance, and shot dispersion are then calculated to evaluate shooting performance.

Based on the computed statistical values, a rule-based knowledge system classifies the observed shooting pattern into mechanical, physical, or mental error categories. Finally, the system generates corrective recommendations that can assist shooters and coaches in improving performance and training effectiveness.

V. Dataset and Knowledge-based Error Classification Framework

This study employs a rule-based dataset to analyze and classify shooting performance errors using spatial shot distribution obtained from target images. Detected pellet impact coordinates are transformed from pixel space to target-relative Cartesian coordinates (in millimeters), and statistical parameters such as group center, group size, mean radial distance, and standard deviation are computed from a standardized 10-shot sample. Based on these parameters, errors are categorized into three primary domains: mechanical, physical, and mental. Mechanical errors are inferred from systematic horizontal or vertical shifts of the group center beyond a defined threshold (± 1.5 mm), and include trigger-induced lateral deviations, recoil anticipation causing low shots, and heeling effects producing high impacts. Physical errors are identified through excessive group dispersion (greater than 7.0 mm) or disproportionate vertical spread, indicating factors such as hold instability, muscular fatigue, or inconsistent breathing patterns. Mental errors are detected by identifying statistical outliers that deviate significantly from the mean radial distance, suggesting lapses in focus or disruption of the shooting routine. Each error category is associated with a structured knowledge base linking observed shot patterns to probable causes and corrective recommendations, enabling interpretable and actionable feedback. This dataset-driven framework integrates image processing, statistical analysis, and expert-derived heuristics to provide an objective assessment of shooting performance suitable for training and performance evaluation applications.

VI. Results and Discussion

The developed system effectively analyses shooting target images to quantify shot accuracy and consistency using image processing and statistical analysis. Pellet impacts are detected and converted into target-relative coordinates, from which a standardized 10-shot group is selected for evaluation. Key performance metrics such as group center, group size, and radial shot dispersion are computed. Systematic horizontal or vertical shifts of the group center indicate mechanical errors, while excessive group spread or dominant vertical dispersion reflects physical factors such as hold instability or breathing inconsistency. Statistically significant outlier shots are associated with mental lapses in focus or routine execution. The results demonstrate that integrating spatial statistics with a rule-based knowledge dataset enables objective and interpretable diagnosis of shooting performance, providing actionable feedback for training applications.

TABLE I. SAMPLE PERFORMANCE ANALYSIS RESULTS

Parameter	Value
Number of Shots	10
Group Size	6.2 mm
Mean Radial Distance	2.8 mm
Standard Deviation	1.4 mm
Error Category	Mechanical

Note: The results indicate that the proposed system can successfully detect pellet impacts, analyse shot grouping behaviour, and provide interpretable error classification for practical training applications.

VII. CONCLUSION

This paper presented an automated ten-shot pistol target analysis system using computer vision and statistical rule-based techniques. The proposed system successfully detects pellet holes from target images, converts shot positions into real-world coordinates, and performs detailed group analysis. By classifying shooting errors into mechanical, physical, and mental categories, the system provides meaningful and objective feedback that can assist shooters and coaches during training.

The experimental results demonstrate that the system offers reliable and repeatable analysis while eliminating subjectivity associated with manual target evaluation. Although the system performs effectively under standard conditions, its accuracy can be further improved by addressing variations in lighting and image quality. Overall, the proposed approach provides a low-cost, efficient, and practical solution for modern shooting performance evaluation.

FUTURE SCOPE

The proposed pistol target analysis system can be further enhanced in several ways. Automatic scale calibration using target ring detection can be implemented to improve measurement accuracy under different camera distances and image resolutions. Adaptive thresholding techniques may be used to improve pellet hole detection in varying lighting conditions.

Machine learning models can be integrated to learn shooting patterns and provide more advanced error prediction and personalized feedback. The system can also be extended into a web-based or mobile application to allow remote performance analysis and long-term shooter data tracking. Additionally, integration with electronic scoring targets and real-time visualization tools can further improve usability and applicability in professional training environments.

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